

Balloons and Gas Laws

Thomas L. Morton

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Introduction

What will happen to our balloon?

- n It will rise
- n It will expand while rising
- n It will pop, and fall back to earth
- n We will talk about the physics of each of these steps.

Topics of Discussion

- n How do gases behave?
- n Why does a helium balloon rise?
 - u What is helium?
- Why does the balloon expand?
- n How much can it lift?
- n How fast does it go up?
- n How far does it go up?

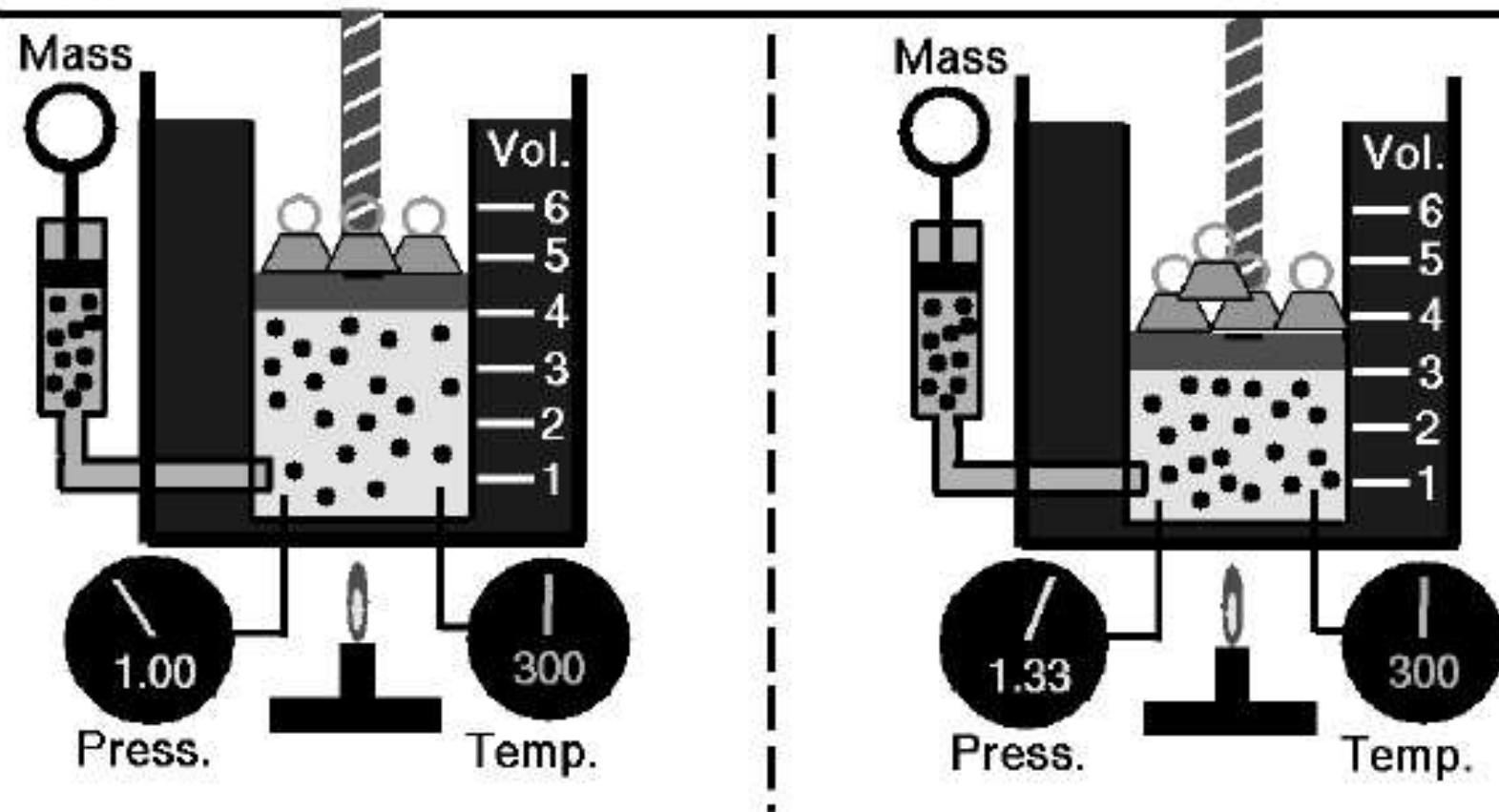
How do gases behave?

- n Boyle's Law – $PV = \text{const}$
- n Charles' Law – $V = \text{const} \times T$
- n Avogadro's Law – Equal volumes at the same temperature and pressure have the same number of molecules. $V = n V_{\text{standard}}$



Boyle's Law

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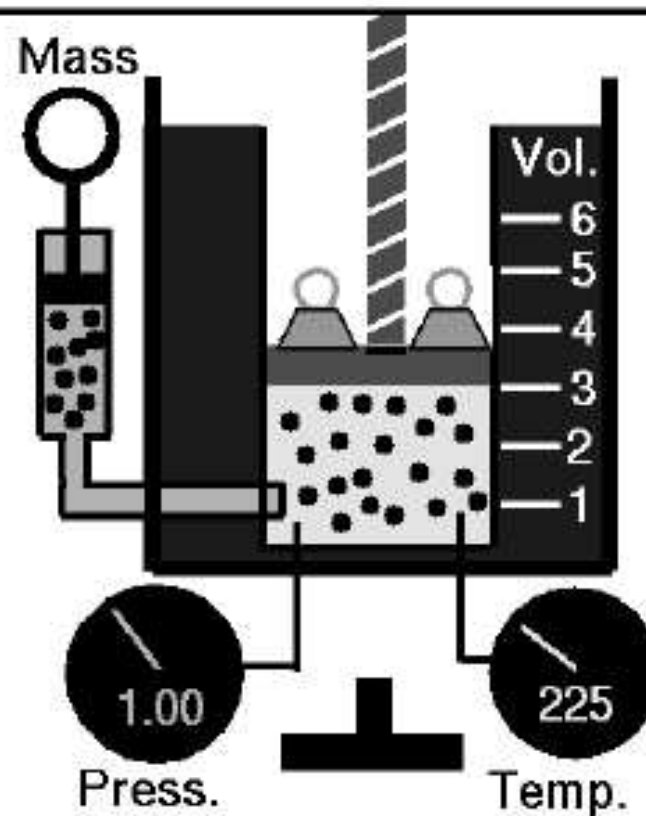
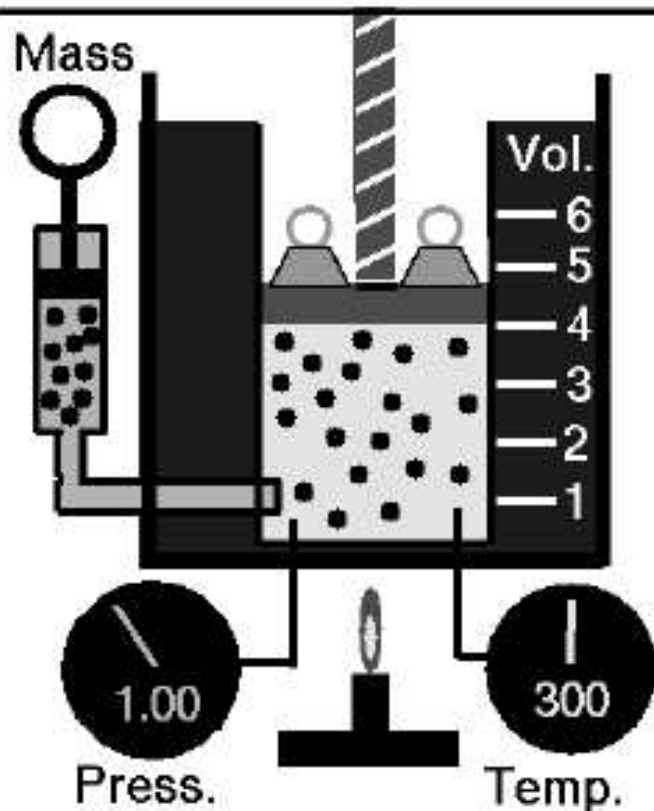
For a given mass, at constant temperature, the pressure times the volume is a constant.

$$p V = C$$



Charles and Gay-Lussac's Law

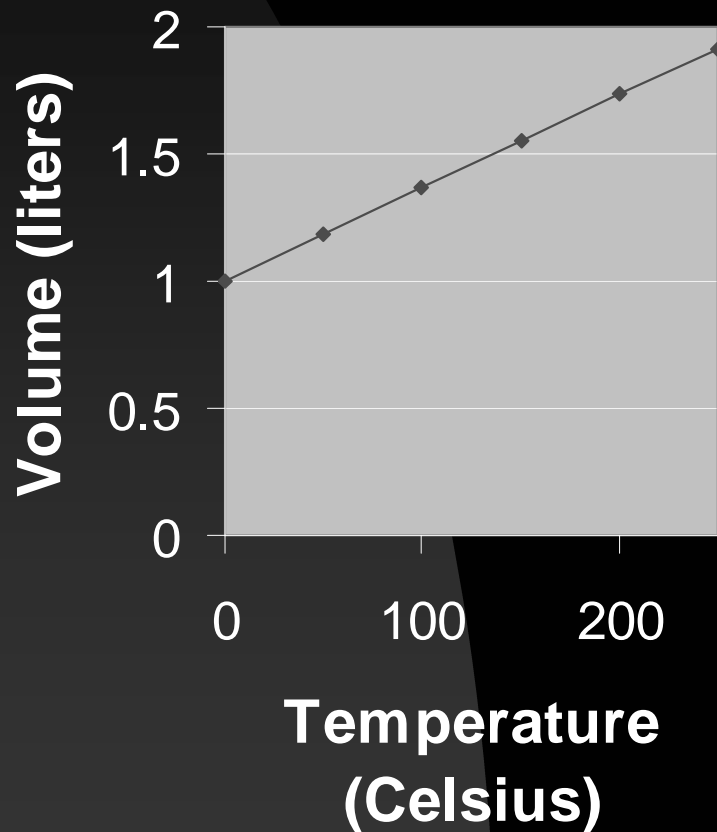
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For a given mass, at constant pressure, the volume is directly proportional to the temperature

$$V = C T$$

What is the Temperature?



- n Volume doesn't go to zero at 0° Celsius
- n Volume does go to zero at -273° Celsius
- n -273 is defined as Absolute Zero
- n We use a Temperature scale called Kelvin
- n $^{\circ}\text{Celsius} + 273 = ^{\circ}\text{Kelvin}$

How do gases behave?

- n Boyle's Law – $PV = \text{const}$
- n Charles' Law – $V = \text{const} \times T$
- n Avogadro's Law – $V = n V_{\text{standard}}$
- Net result – $PV / nT = R$
- R is the gas constant
 - u $R = 8.314 \text{ J / K mol}$
 - u $R = 1.987 \text{ cal / K mol}$
 - u $R = .08205 \text{ liter atm / K mol}$

What is n?

- n In a typical liter of air, there are about 2.7×10^{22} molecules.
- n Scientists use a different counting scale.
A gram equivalent of a chemical is called a mole.
- n 1 mole = 6.02×10^{23} molecules/atoms

The Periodic Table of Elements

1 H HYDROGEN 1																	2 He HELIUM 4																		
3 Li LITHIUM 7	4 Be BERYLLIUM 9																	5 B BORON 11	6 C CARBON 12	7 N NITROGEN 14	8 O OXYGEN 16	9 F FLUORINE 19	10 Ne NEON 20												
11 Na SODIUM 23	12 Mg MAGNESIUM 24																	13 Al ALUMINUM 27	14 Si SILICON 28	15 P PHOSPHORUS 31	16 S SULFUR 32	17 Cl CHLORINE 35	18 Ar ARGON 40												
19 K POTASSIUM 39	20 Ca CALCIUM 40	21 Sc SCANDIUM 45	22 Ti TITANIUM 48	23 V VANADIUM 51	24 Cr CHROMIUM 52	25 Mn MANGANESE 55	26 Fe IRON 56	27 Co COBALT 59	28 Ni NICKEL 59	29 Cu COPPER 64	30 Zn ZINC 65	31 Ga GALLIUM 70	32 Ge GERMANIUM 73	33 As ARSENIC 75	34 Se SELENIUM 79	35 Br BROMINE 80	36 Kr KRYPTON 84	37 Rb RUBIDIUM 85	38 Sr STRONTIUM 88	39 Y YTTRIUM 89	40 Zr ZIRCONIUM 91	41 Nb NIOBIUM 93	42 Mo MOLYBDENUM 96	43 Tc TECHNETIUM 98	44 Ru RUTHENIUM 101	45 Rh RHODIUM 103	46 Pd PALLADIUM 106	47 Ag SILVER 108	48 Cd CADMIUM 112	49 In INDIUM 115	50 Sn TIN 119	51 Sb ANTIMONY 122	52 Te TELLURIUM 128	53 I IODINE 127	54 Xe XENON 131
55 Cs CESIUM 133	56 Ba BARIUM 137																	72 Hf HAFNIUM 178	73 Ta TANTALUM 181	74 W TUNGSTEN 184	75 Re RHENIUM 186	76 Os OSMIUM 190	77 Ir IRIDIUM 192	78 Pt PLATINUM 195	79 Au GOLD 197	80 Hg MERCURY 201	81 Tl THALLIUM 204	82 Pb LEAD 207	83 Bi BISMUTH 209	84 Po POLEONIUM 209	85 At ASTATINE 210	86 Rn RADON 222			
87 Fr FRANCIUM 223	88 Ra RADIUM 226																	104 Rf RUTHENIUM 263	105 Db DUBNIUM 268	106 Sg SEABORGIUM 266	107 Bh BOHRIUM 272	108 Hs HASSIUM 277	109 Mt MEITNERIUM 276	110 Ds DAIRSGAUMIUM 281	111 Rg ROSGAUMIUM 280	112 Uub UNUNBIUM 285	113 Uut UNUNTRIUM 284	114 Uuq UNUNQUADIUM 289	115 Uup UNUNPENTIUM 288	116 Uuh UNUNHEXIUM 292	117 Uus UNUNSEPTIUM 294	118 Uuo UNUNOCTIUM 294			

6

C

CARBON

12

Atomic Number = Number of Protons = Number of Electrons

Chemical Symbol

Chemical Name

Atomic Weight = Number of Protons + Number of Neutrons

NON-METALS

METALS

6 ← Atomic Number = Number of Protons = Number of Electrons

C ← Chemical Symbol

CARBON ← Chemical Name

12 ← Atomic Weight = Number of Protons + Number of Neutrons*

NON-METALS

METALS

KEY

- ☐ = Solid at room temperature
- ☉ = Liquid at room temperature
- ☁ = Gas at room temperature
- ☛ = Radioactive
- ☞ = Artificially Made

57 La LANTHANUM 139	58 Ce CELIUM 140	59 Pr PRASEODYMIUM 141	60 Nd NEODYMIUM 144	61 Pm PROMETHIUM 145	62 Sm SAMARIUM 150	63 Eu EUROPIUM 152	64 Gd GADOLINIUM 157	65 Tb TERBIUM 159	66 Dy DYSPROSIUM 163	67 Ho HOLMIUM 165	68 Er ERBIUM 167	69 Tm THULIUM 169	70 Yb YTERBIUM 173	71 Lu LUTETIUM 175
89 Ac ACTINIUM 227	90 Th THORIUM 232	91 Pa PROTACTINIUM 231	92 U URANIUM 238	93 Np NEPTUNIUM 237	94 Pu PLUTONIUM 244	95 Am AMERICIUM 243	96 Cm CURIUM 247	97 Bk BERKELIUM 247	98 Cf CALIFORNIUM 251	99 Es EINSTEINIUM 252	100 Fm FERMIUM 257	101 Md MESEBERIUM 258	102 No NOBELIUM 259	103 Lr LAWRENCIUM 262

* The atomic weights listed on this Table of Elements have been rounded to the nearest whole number. As a result, this chart actually displays the mass number of a specific isotope for each element. An element's complete, unrounded atomic weight can be found on the IUPAC Elemental web site: <http://education.jlab.org/elemental/index.html>

Ideal Gas Law

n Finally, we have $PV = nRT$

- u P in atmospheres

- u V in liters

- u n in moles

- u T in kelvins

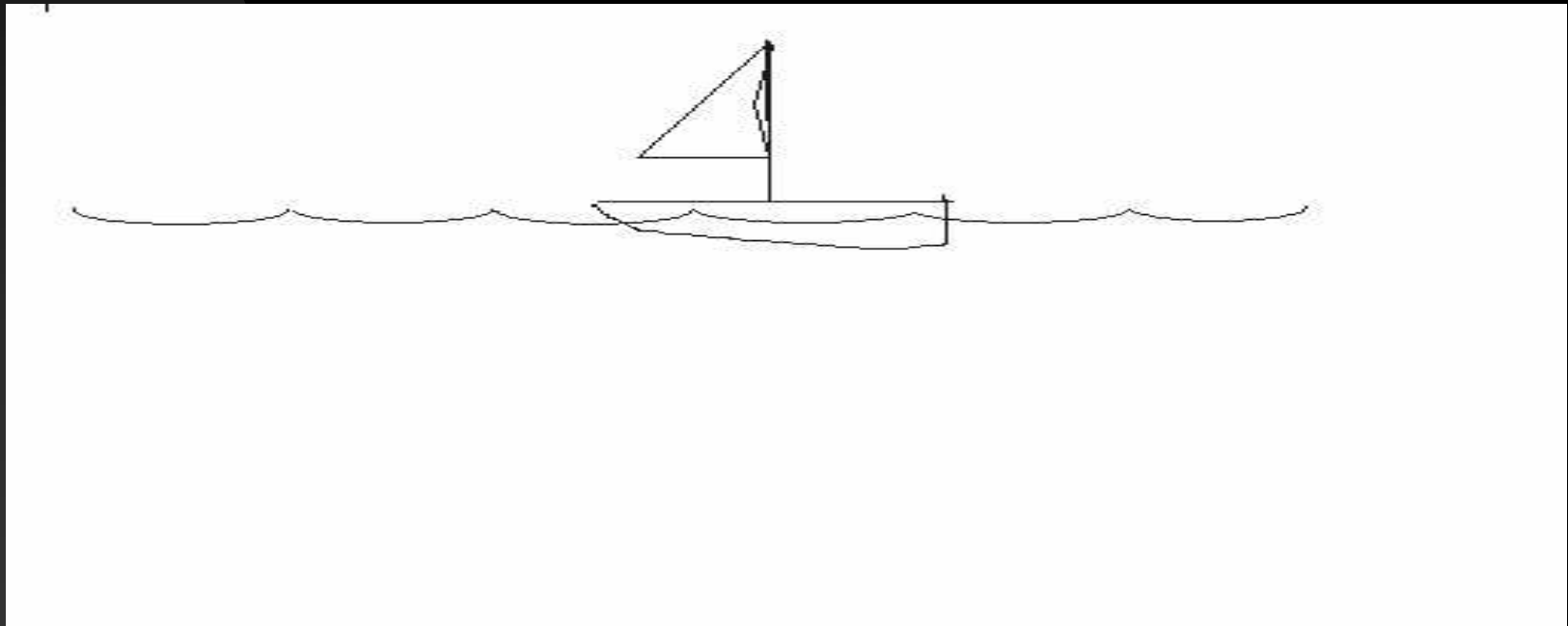
- u $R = 0.08205 \text{ liter atm / K mol}$

n Valid for moderate temperatures and pressures.

n OK for conditions we will see

Why do Helium balloons float?

n Why do boats float?



Why do Helium balloons float?

- § Helium balloons “float” in a sea of air.
 - § Helium weighs less than air.
 - § Displaces more dense air where balloon is.
- Air is 78% Nitrogen, 21% Oxygen, and 1% Argon
- n Molecular weight of air is
$$0.78 \times 28 + 0.21 \times 32 + 0.01 \times 40 = 28.96 \text{ g/mol}$$
- n “Molecular” weight of Helium is 4 g/mol

Let's use the ideal gas law

n Suppose I have a balloon one foot in diameter

n $\text{Volume} = 4\pi r^3/3 = 4\pi(15.24 \text{ cm})^3 / 3 = 14,800\text{cm}^3 = 14.8 \text{ liters.}$

Weight of that air is:

$$14.8/ (.08205 * 298) * 28.96 = 17.5 \text{ gm}$$

Weight of helium is:

$$14.8/ (.08205 * 298) * 4 = 2.4 \text{ gm}$$

W Lift is $17.5 - 2.4 = 15.1 \text{ gm.}$

W Rises if balloon weight is less than 15.1 gm

What is the relevance to balloons?

- n Tube demonstration
- n Measure pressure in different sized balloons
- n Recover balloon from freezer
- Lift equation is a little different
 - u Use P_{internal} for the weight of balloon and Helium
 - u Lift is a little less than previous slide

What happens as balloon rises?

- n Pressure drops
- n Temperature drops, then stays steady
- n Consider balloon from a couple slides ago, at 10,000 feet high
 - u $P = 700 \text{ mBar} = .69 \text{ atmospheres}$
 - u $T = 0^\circ \text{ C} = 273 \text{ kelvins}$
 - u $n = .61 \text{ moles}$
 - u $V = nRT / P = 19.6 \text{ liters}$
 - u $R = \sqrt[3]{3 \cdot V / (4\pi)} = 16.7 \text{ cm} > 15.2 \text{ cm}$

What happens as balloon rises? (2)

Σ Consider the same balloon, now at 50,000 feet

- u $P = 120 \text{ mBar} = .12 \text{ atmospheres}$

- u $T = -60^\circ \text{ C} = 213 \text{ kelvins}$

- u $n = .61 \text{ moles}$

- u $V = nRT / P = 88.2 \text{ liters}$

- u $R = \sqrt[3]{3 \cdot V / (4\pi)} = 27.6 \text{ cm} \approx 2 \times 15.2 \text{ cm}$

What happens as balloon rises? (3)

Consider the same balloon, now at 100,000 feet

- u $P = 10 \text{ mBar} = .01 \text{ atmospheres}$
- u $T = -50^\circ \text{ C} = 223 \text{ kelvins}$
- u $n = .61 \text{ moles}$
- u $V = nRT / P = 1160 \text{ liters}$
- u $R = \sqrt[3]{3 \cdot V / (4\pi)} = 65.1 \text{ cm} \approx 4 \times 15.2 \text{ cm}$
- u Balloon stretched to 18 x original surface area
- u Balloon thickness starts at .28 mm, goes to .015 mm

Activities

- n Measure balloon size, lift, and rise rate:
 - u Use string to measure radii.
 - u Use scale to measure weight of balloon, and lift.
 - u Use stopwatch to measure time to rise from floor to ceiling.
- n Use vacuum tank to measure balloon size as a function of pressure.